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A COLD-STORAGE EVAPORIMETER.[a]

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INTRODUCTION.

In the cold storage of food products the control of temperature has been reduced to a very satisfactory basis. The thermometer as a means of temperature measurement is practically perfect. Other than temperature, the most important factor in the success of such operations is the humidity or amount of evaporation, but heretofore there has been no instrument for determining humidity that would meet the demands of this industry.

Animal products in particular suffer loss from unfavorable conditions of atmospheric moisture. In the case of eggs, for example, if the air of the storage room is too dry the eggs lose weight by evaporation and are thereby seriously impaired in quality. On the other hand, if the air surrounding the eggs approaches too closely to the saturation point, even for a short period, fungous growths develop upon the eggs and packing material, imparting a musty flavor to the eggs. The end to be attained in egg storage, therefore, is to reduce evaporation as much as possible without causing mustiness, and it is important to have some means by which the evaporating power of a cold-storage room may be accurately determined. An instrument devised by the writer and constructed for this purpose is described in the following pages. It has been tested in two of the largest egg-storage plants in Chicago with good results, and it is believed to be applicable also to other branches of the storage industry.

[a] United States patent (No. 454280) on the apparatus herein described has been granted under the act of Congress of March 3, 1883, so that the apparatus may be used by the Government of the United States, or any of its officers or employees in the prosecution of work for the United States, or by any person in the United States, without the payment of royalty.

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When water is exposed to the air it evaporates; in other words, invisible particles of water vapor pass into the atmosphere. Like other gaseous matter, these vapor particles exert a certain definite pressure which increases more and more as the number of particles increases. Ultimately, however, as the evaporation proceeds, and supposing the vapor particles are not carried away, a maximum vapor pressure is reached, called the saturation pressure. When a condition of saturation exists, particles of vapor still continue to be given off by the water just the same as before, but this evaporation is just counterbalanced by an equal number of particles passing from the vapor back into the liquid, so that a state of equilibrium at the maximum pressure is constantly maintained.

The saturation pressure increases with temperature. At 212° F. the vapor pressure equals the normal atmospheric pressure, viz, 30 inches of mercury, and at this temperature and pressure water boils, as we say. At cold-storage temperatures the vapor pressure is much less, as, for example, 0.180 inch of mercury at 32° F.

When the temperature of saturated water vapor is lowered water is generally formed by condensation. This occurs in nature as cloud, fog, rain, snow, etc., except that vapor wholly devoid of dust or other minute foreign particles, which when present, act as nuclei for the condensation, may require to be cooled somewhat below the point of saturation before condensation actually occurs. When thus undercooled the vapor is said to be supersaturated.

At a given temperature the pressure of the vapor in the air may vary from nothing up to the saturated pressure for that temperature. Suppose, for example, that at a temperature of 32° F. the actual vapor pressure is 0.135 inch. This would be only three-fourths of 0.180, the saturated pressure at that temperature. The term "absolute humidity" is used to mean the actual vapor pressure and sometimes the weight of a unit volume of vapor. The term "relative humidity" is used to mean the ratio between the actual pressure of the vapor present and that required for saturation at the same temperature. In the foregoing example this would be the ratio between 0.135 and 0.180; that is, three-fourths, or 75 per cent. Both of these terms, though long used, are confusing as misapplied to cold-storage practice. A table which has been widely used in the cold-storage trade gives the relative humidities for egg rooms at different temperatures, the figures being based on a constant absolute humidity. As the saturation deficit changes more rapidly when the absolute humidity is held constant than when the relative humidity is held constant, this table gives a result diametrically the opposite of what its author evidently intended, i. e., a uniform rate of evaporation. That the error was not

discovered in practice is due to the practical uniformity of temperatures at which eggs are held. What we wish to know is the rate of evaporation. This is best expressed by the difference between the actual vapor pressure and the saturation vapor pressure of water at the same temperature. In the foregoing case this is the difference between 0.180 and 0.135; that is, 0.045. This difference is called the saturation deficit.

For example: Room A at a temperature of 25° F. has a vapor pressure of 0.104; room B at 28° has a pressure of 0.120; room C at 45° has a pressure of 0.238. At 25° the saturation vapor pressure is 0.130. The relative humidities would therefore be: Room A, $0.104 \div 0.130 = 80$ per cent; room B, $0.120 \div 0.150 = 80$ per cent; room C, $0.238 \div 0.298 = 79.8$ per cent. But the saturation deficits would be: A, $0.130 - 0.104 = 0.026$; B, $0.150 - 0.120 = 0.030$; C, $0.298 - 0.238 = 0.060$. As these last figures show the difference between the pressure of the vapor in the air and that required for saturation, they indicate approximately by Dalton's law the rate at which evaporation would take place. Thus, room C with practically the same relative humidity as room B would shrink a product twice as fast.

PRINCIPLE OF THE EVAPORIMETER.

If some substance be dissolved in water the saturation vapor pressure of the solution is lowered to an amount dependent upon the nature of the substance used and the strength of the solution. The vapor pressure of a solution, like that of pure water, changes with the temperature and always bears nearly a constant ratio to that of pure water at the same temperature. Thus a solution that has a vapor pressure of 0.090 at 32° F., which is half the pressure of water at that temperature, would have a pressure of 0.065 at a temperature of 25° F.—one-half that of water at that temperature.

When vapor at any given pressure is in contact with a neutral[a] surface, condensation, that is, dew, frost, etc., will be deposited upon the surface whenever its temperature is below the saturation temperature that corresponds to the vapor pressure as it actually exists.

Hygroscopic substances like hair, wool, sulphuric acid solutions, and a great many other bodies are not neutral surfaces, but have the power themselves to absorb and give off vapor. With all such bodies

[a] A neutral surface in this connection is one that is chemically inert to water, such as clean or polished metal surfaces, for example. Strictly speaking, it may be a question whether an absolutely neutral surface exists, except pure water itself. All other surfaces may in greater or less degree either absorb or condense moisture before the saturation temperature is reached, or else have to be cooled, at least slightly, below the point of condensation before dew is actually deposited.

there is a certain more or less definite equilibrium vapor pressure at which absorption and evaporation equalize each other. When the vapor pressure around one of these bodies is below the equilibrium point, evaporation from the body will occur, but when the pressure is above this point the body will absorb moisture from the medium.

If we have vapor at a pressure of 0.200, water in one receptacle at a temperature such that the saturation pressure is 0.250 and an acid solution in another receptacle whose equilibrium vapor pressure is 0.150, then the water will evaporate, but the acid will absorb moisture and at nearly the same rate. On the other hand, if we prepare a solution whose equilibrium pressure is 0.200 at the particular temperature that prevails, then such a solution will neither gain nor lose in the presence of vapor at a pressure of 0.200. If the vapor pres-

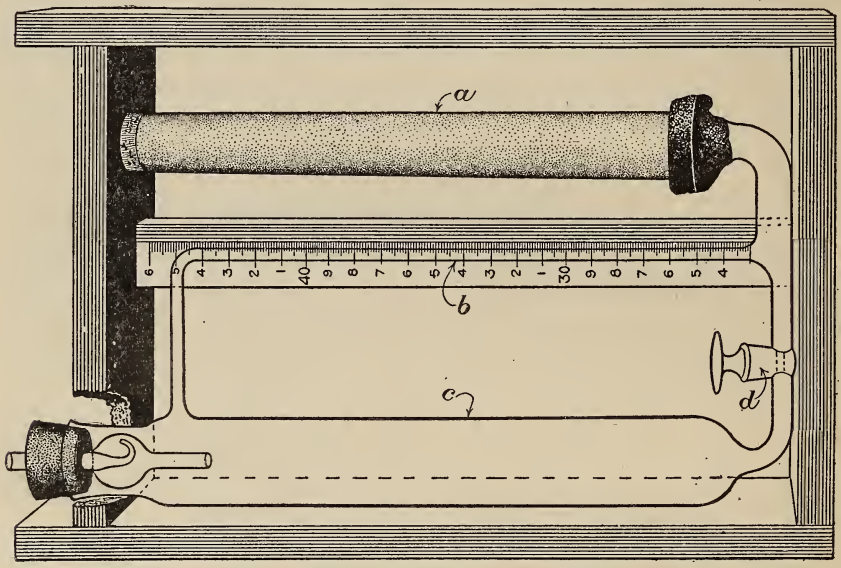

FIG. 1.—The cold-storage evaporimeter: *a*, Porous tube; *b*, reading tube; *c*, reservoir; *d*, stopcock.

sure of the air changes the change will immediately be shown in the consequent beginning of evaporation or condensation.

It follows that with a standard solution and an instrument to measure these changes we would have a reliable guide for the regulation of humidity. The cold-storage evaporimeter devised by the writer is based on these principles.

DESCRIPTION OF THE EVAPORIMETER.

The essential parts of this instrument are:

1. A porous porcelain tube (fig. 1, *a*) through which the liquid may be exposed to the air. (In the writer's experiments a Pasteur filter

tube was used.) The volume of liquid in this tube remains constant, the fluctuation due to evaporation or condensation being registered in the reading tube connected with the porous tube. This porcelain tube must be kept in a horizontal position and must be kept above the level of the liquid in other portions of the apparatus. The liquid will be maintained in the porous tube by capillary attraction, while if this tube were held lower than the other portions of the apparatus, pressure would cause a seepage of liquid through the filter tube.

2. A graduated reading tube (*b*) of such bore that the changes in volume of the liquid may be readily observed. (A tube of 3 mm. inside diameter was used by the writer.) This tube empties into the reservoir, and gives a double passageway, so that the instrument may be readily filled and emptied.

3. A reservoir (*c*), provided with a check bulb to allow freedom of air pressure without leaking of the liquid.

4. A stopcock (*d*) by which the amount of liquid in the porous tube may be regulated so as to keep the surface within the reading scale.

5. A suitable supporting frame.

The device used to contain the solution is similar to a water-containing evaporimeter described by Livingston (1906) of the Desert Laboratory of the Carnegie Institution.

STANDARD SOLUTION USED.

Sulphuric acid is recommended as the most suitable liquid to use in the evaporimeter. The ordinary commercial acid that can be secured at any drug store is satisfactory. This is diluted with water until the mixture assumes the specific gravity desired. The specific gravity must be read with a hydrometer graduated to thousandths when the liquid is at a temperature of exactly 32° F. This can easily be done if the acid is mixed in a cold room and both water and ice (or pipe frost) are used in diluting it. Care should be taken in handling the acid, as, if it is mixed too rapidly with water, enough heat will be generated to crack glass vessels. The acid should be poured slowly into the water. Water should never be poured into concentrated acid.

Enough acid of a desired strength may be mixed at one time to allow many changes of the solution in the evaporimeter. A gallon or half-gallon bottle should be used to hold the prepared acid and should be kept in a room of the same temperature as that in which it is to be used. The acid bottle should be kept tightly closed.

The following table gives the specific gravity of the acid solution, its saturation vapor pressure, the corresponding equilibrium, relative humidity, and saturation deficit, all at 32° F.

Table showing specific gravity of aqueous sulphuric acid, saturation vapor pressure, equilibrium, relative humidity, and saturation deficit, at 32° F.[a]

Specific gravity.	Saturation vapor pressure at 32° F.	Equilibrium, relative humidity.	Saturation deficit.	Specific gravity.	Saturation vapor pressure at 32° F.	Equilibrium, relative humidity.	Saturation deficit.
	Inches of mercury.	*Per cent.*			*Inches of mercury.*	*Per cent.*	
[b] 1.00	0.1800	100.0	0.0000	1.16	0.1573	87.4	0.0227
1.01	.1792	99.5	.0008	1.17	.1542	85.7	.0258
1.02	.1784	99.1	.0016	1.18	.1512	84.0	.0288
1.03	.1776	98.7	.0024	1.19	.1481	82.3	.0319
1.04	.1767	98.2	.0033	1.20	.1450	80.5	.0350
1.05	.1756	97.5	.0044	1.21	.1417	78.7	.0383
1.06	.1744	96.9	.0056	1.22	.1380	76.7	.0420
1.07	.1732	96.2	.0068	1.23	.1343	74.6	.0457
1.08	.1721	95.6	.0079	1.24	.1306	72.5	.0494
1.09	.1706	94.8	.0094	1.25	.1268	70.4	.0532
1.10	.1691	93.9	.0109	1.26	.1225	68.0	.0575
1.11	.1678	93.2	.0122	1.27	.1180	65.5	.0620
1.12	.1662	92.3	.0138	1.28	.1136	63.1	.0664
1.13	.1641	91.2	.0159	1.29	.1092	60.7	.0708
1.14	.1619	89.9	.0181	1.30	.1050	58.3	.0750
1.15	.1598	88.8	.0202				

[a] This table is prepared by the Biochemic Division of the Bureau of Animal Industry and is based on experimental results by C. Dieterici as published in Wiedemann's "Annalen der Physik und Chemie," vol. 50, 1893, pp. 60 and 69, recalculated to pressure in inches of mercury at a barometric pressure of 30 inches and on the basis that the saturation pressure of water at 32° F. is 0.180 inch of mercury.

[b] Water.

This table can be computed for any temperature as follows: The relative humidity for a given specific gravity of acid (always measured at 32° F.) remains the same at all temperatures. The absolute humidity or vapor pressure of the acid is determined by multiplying the relative humidity by the vapor pressure of pure water at the given temperature. The saturation deficit is determined by subtracting the acid pressure from the pressure of water.

EXAMPLE: At 28° F. the relative humidity of 1.20 acid is 0.805.
0.805×0.150 (the vapor pressure of water)=0.1207=saturation pressure at 28°.
0.150−0.1207=0.0293, the saturation deficit at 28° F.

The specific gravity of acid solution required to give certain saturation deficits from common egg-room temperatures are given in the following table:

Table showing specific gravity of sulphuric acid solution for certain saturation deficits at temperatures given.

Temperature.	Saturation deficit.				
	0.010.	0.020.	0.030.	0.040.	0.050.
° F.	*Sp. gr.*	*Sp. gr.*	*Sp. gr.*	*Sp. gr.*	*Sp. gr.*
29	1.104	1.161	1.198	1.230	1.259
30	1.100	1.157	1.193	1.225	1.254
31	1.097	1.153	1.188	1.220	1.247
32	1.094	1.149	1.184	1.215	1.241
33	1.092	1.145	1.180	1.210	1.236

In practice, as the temperature of a plant is uniform, it would be sufficient to define the humidity by referring to the specific gravity of acid used. Thus a plant with dead air might be held

at a temperature of 32° F. and an evaporimeter test of 1.19 acid, while another plant with a blower system might find that best results could be obtained with a temperature of 30° F. and an evaporimeter test of 1.17 acid.

OPERATION OF THE INSTRUMENT.

Filling.—Hold the evaporimeter with the mouth of the reservoir upward and pour in the solution until the reservoir is three-fourths full. Push the stopper in tightly, holding the reservoir tube firmly in the other hand. See that the hook in the catch bulb is turned toward the porous tube. Now open the stopcock and tilt the frame so that the solution will flow into the porous tube. By tilting the instrument back and forth the porous tube is entirely filled. Allow the instrument to remain a minute or two in the position for draining the solution into the porous tube, until the tube is thoroughly soaked and liquid begins to drip through. Be sure that all bubbles are out of evaporation and reading tubes by holding for a moment with the tubes in a vertical position, with the stopcock at the top. Now close the stopcock and hold the instrument as in figure 1. This is the working position of the evaporimeter. After the globules of liquid which have gathered on the outer surface of the porous tube have disappeared (they may be wiped off with a clean cloth), the liquid may be drawn back into the reading scale by carefully turning the stopcock.

Location.—The instrument may be set on a shelf or hung by cords of sufficient length to allow free manipulation. Drafts of air blowing upon the evaporimeter do not affect its accuracy in determining whether the air is above or below the vapor pressure of the liquid, but, with a given difference of pressure, currents of air will accelerate the rate of change, which fact is also true of the evaporation of the products in storage. By adapting the strength of the solution to the vapor pressure of the air, the evaporimeter may be made to determine the humidity in the center of a pile of cases as well as in a main draft of air, and in the hands of a careful investigator the instrument may be used to determine both the efficiency of air circulation and the evaporating power of various air currents. In the average plant, however, with these factors fixed by the equipment, it will be sufficient to locate the instrument in a center aisle, or if a forced-draft system be used, in the main draft, and from practical experience determine what saturation deficit in this location will give the best results.

Reading.—The instrument when in use must always have the porous tube horizontal and above the reading tube. The readings may be taken as often as desirable and the movement figured on an hourly, daily, or weekly basis (daily would seem preferable). The level of the liquid must be adjusted with the stopcock as often as necessary to keep it from running off the reading scale. When more

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liquid must be run into the reading tube the instrument must be tipped until the reading tube is below the reservoir. This will cause a slight quantity of liquid to ooze through the porous tube, and this must then be allowed to pass back into the tube before the reading is taken, or an error will be introduced. It must be remembered that change of temperature of any liquid causes change of volume, and if the instrument is taken into a warm room or filled with warm liquid time must be allowed for it to reach the same temperature as the air of the storage room before readings are of value. Bubbles will sometimes collect in the evaporation tube and introduce an error in reading. These are due to air held in solution and will not occur except after fresh solution is poured into the evaporimeter.

Refilling.—The instrument would not need refilling if the strength of the solution could be so nicely balanced with the average vapor pressure of the air that the liquid would play back and forth within the confines of the reading tube. In practice this is impracticable; with a reading tube of 3 millimeters bore the error introduced by the weakening or concentration of the solution is such as to require the refilling of the instrument every time the total movement in one direction has amounted to two tube lengths. The frequency with which this must be done will vary with the efficiency of the air control, and the interval may be from three days to three months. The rate of change in strong drafts, as before stated, will be greatly accelerated. This, if predominantly in one direction, will cause too rapid a change in the strength of solution for best results. In such cases it is best to protect a portion of the porous tube from contact with the air by wrapping with waxed paper or other acid-proof material. By this means the rate of change may be adapted to the location of the instrument until a mean is struck, which will give readings sufficient to indicate the changes in humidity and yet affect but slowly the strength of the solution.

Change of solution.—When it is desired to introduce a solution of a different strength it will be necessary to empty the instrument, rinse it, and then fill the tube with water and allow it to stand inverted for a few hours until the porous tube is thoroughly washed. It must then be allowed to dry out before the fresh solution is put in. For ordinary purposes and where the variations are not great it will be sufficient to drain the tube, refill it with fresh acid solution, and then allow a quantity of this acid to filter through the tube.

Approved:

JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *June 25, 1909.*

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